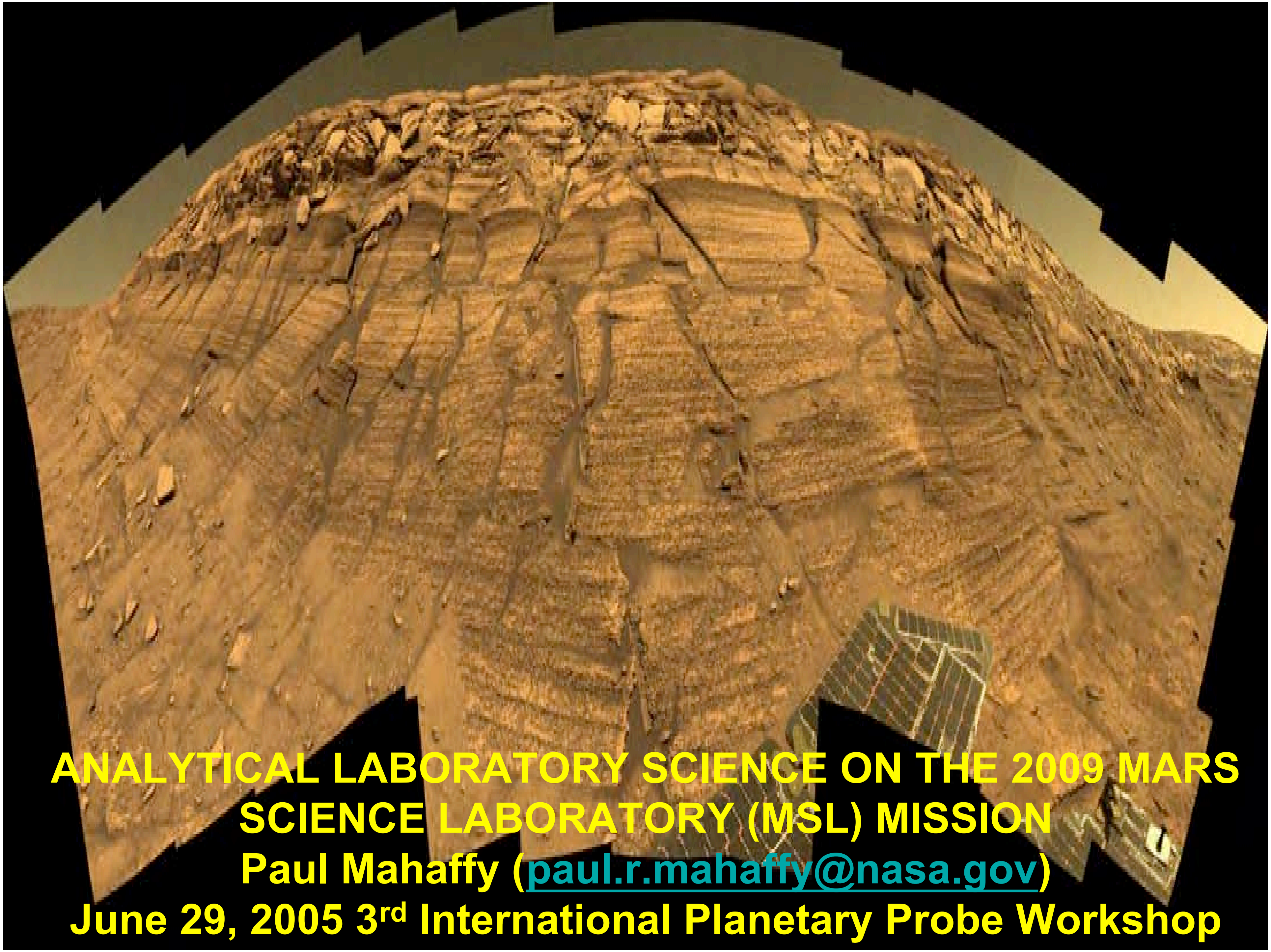


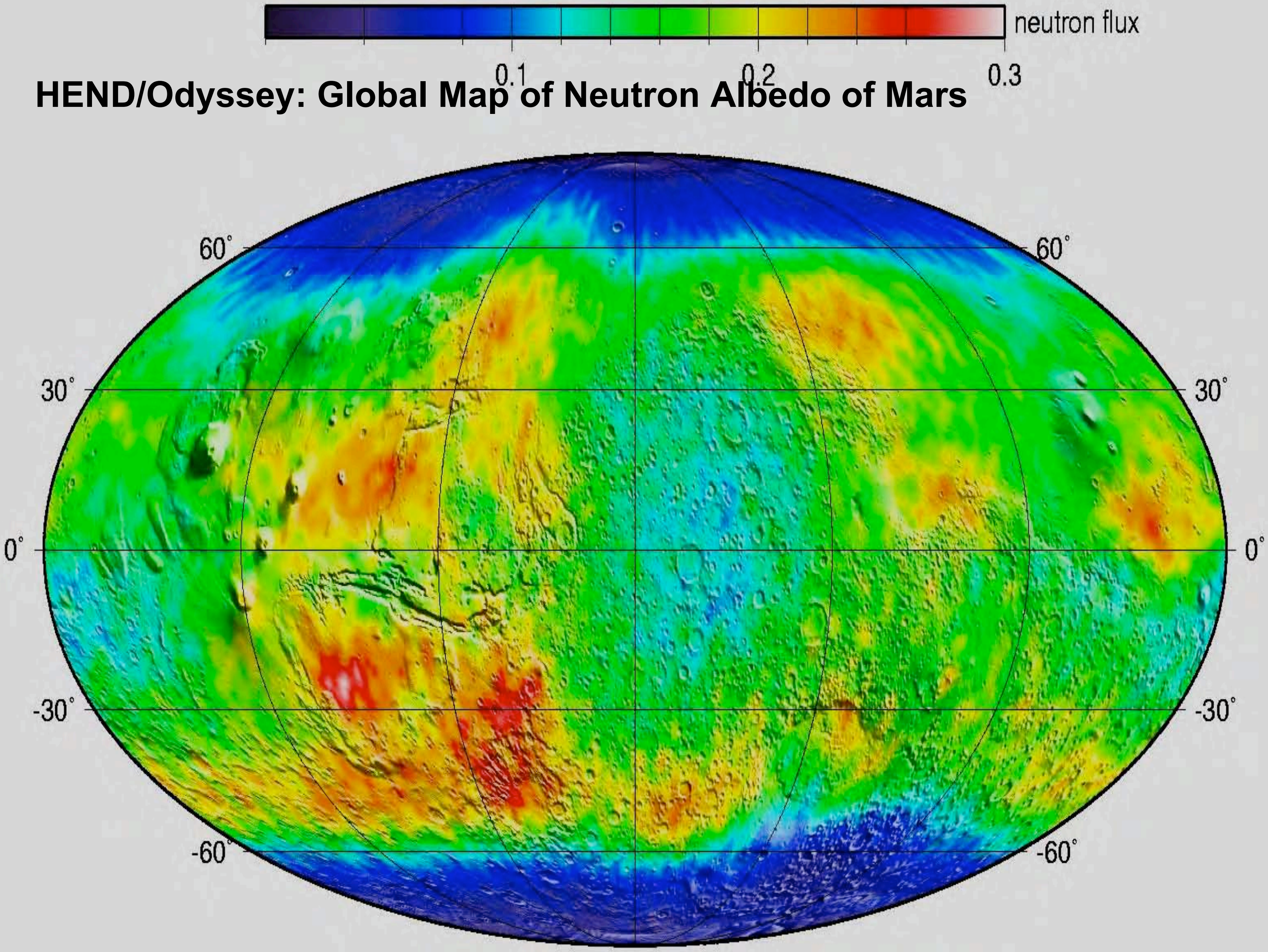
ANALYTICAL LABORATORY SCIENCE ON THE 2009 MARS SCIENCE LABORATORY (MSL) MISSION

Paul Mahaffy (paul.r.mahaffy@nasa.gov)

June 29, 2005 3rd International Planetary Probe Workshop

Context for the MSL investigations – maps of volatiles on Mars

HEND/Odyssey: Global Map of Neutron Albedo of Mars



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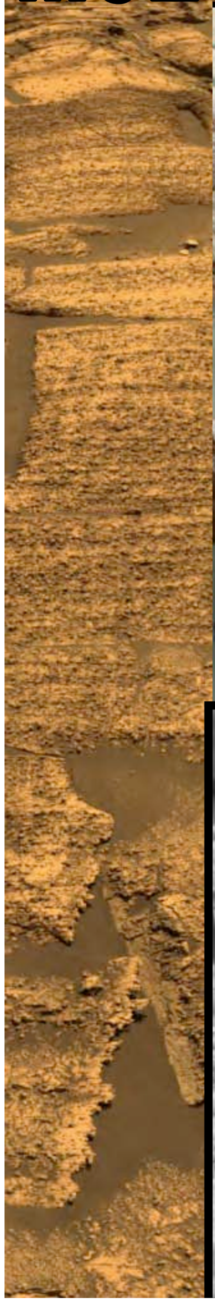
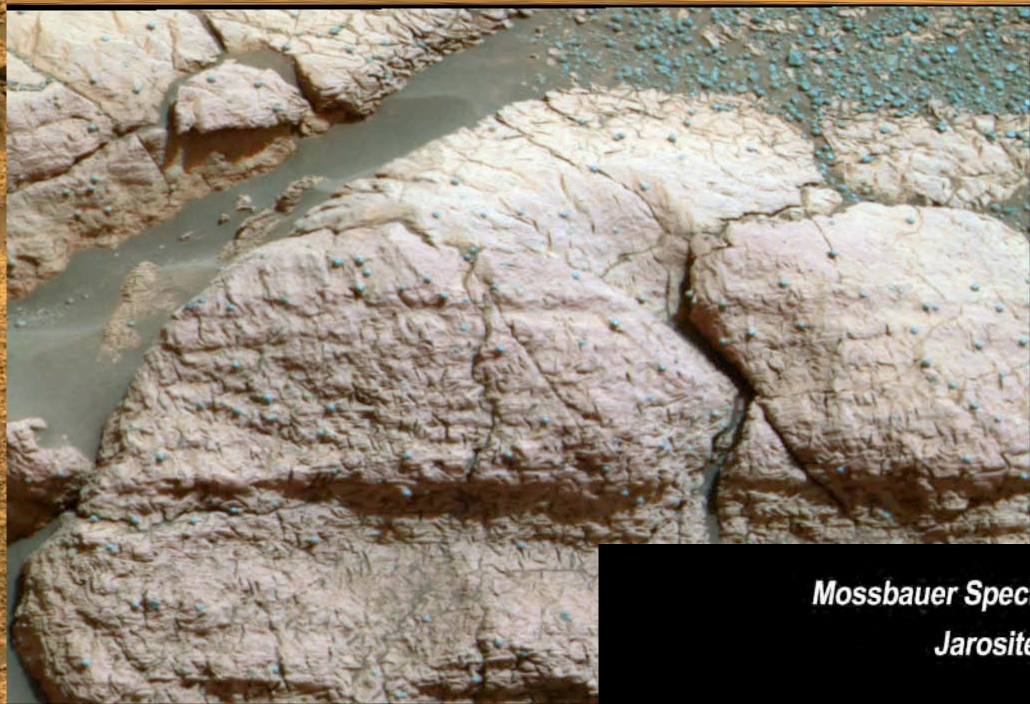
Early MER results showed chemical evidence of aqueous alteration

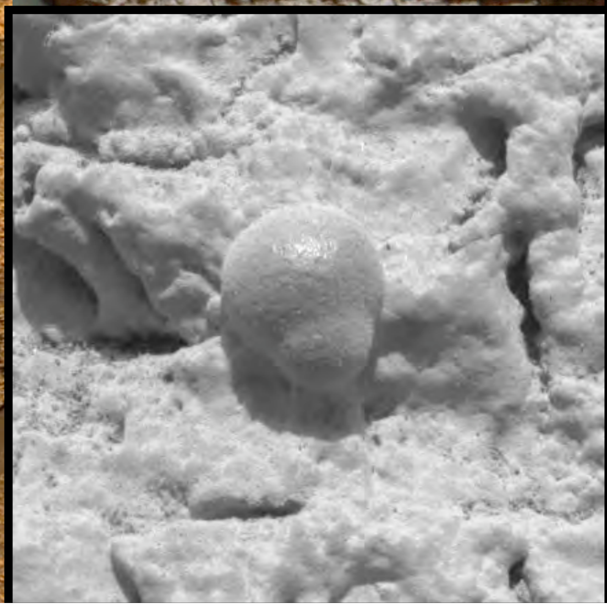


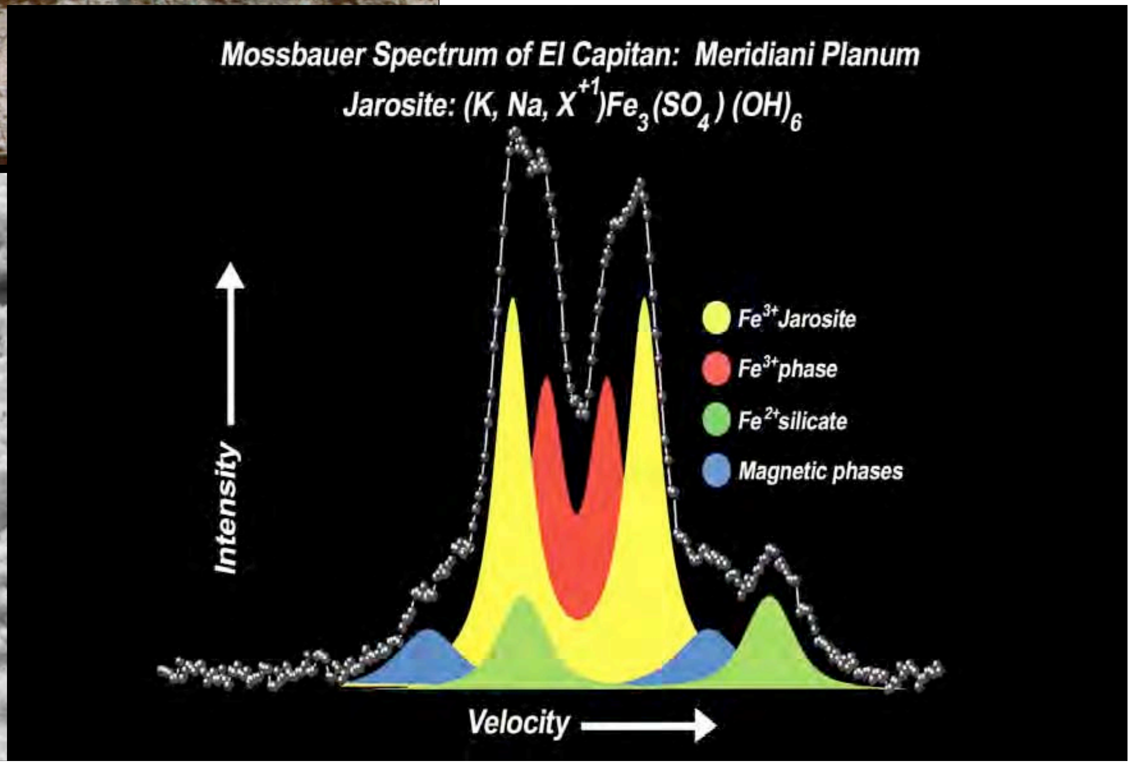


MER observations of

- Vugs
- Spherules
- High sulfur (alpha particle spectrometer) and
- Jarosite – a sulfate (from Mossbauer spectrometry)

→This location was “awash” in liquid water





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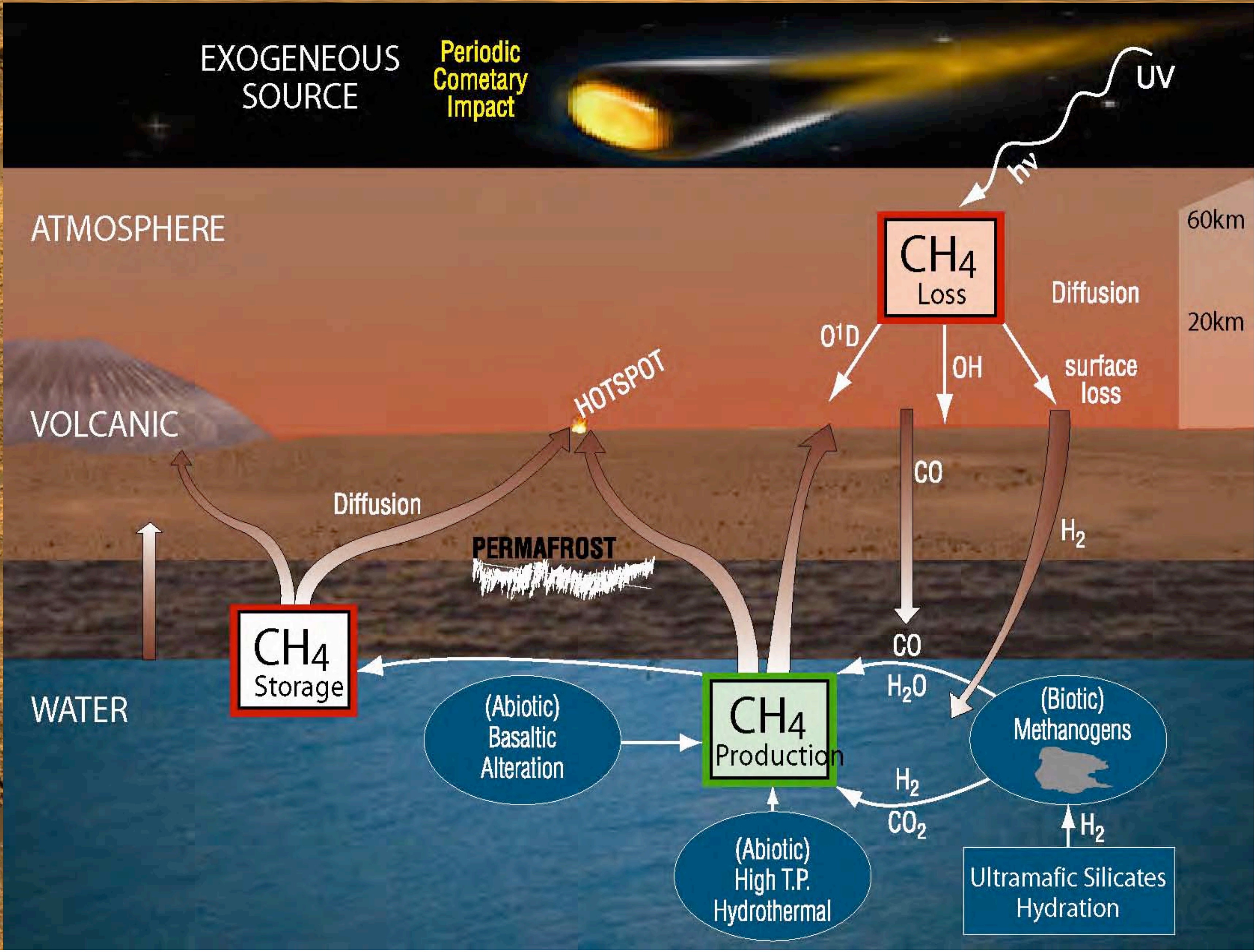
Mars Express and Earth based spectroscopy revealed methane



MSL Project Science Integration Group

Proposed Science Objective:
Mars Science Laboratory

Explore and Quantitatively Assess a Potential Habitat on Mars

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MSL Project Science Integration Group Science Definition

Scientific Investigations Required to Achieve Objective:

A. Assess the biological potential of at least one target environment (past or present).

- i. Determine the nature and inventory of organic carbon compounds.
- ii. Inventory the chemical building blocks of life (C, H, N, O, P, S).
- iii. Identify features that may record the actions of biologically-relevant processes.

B. Characterize the geology of the landing region at all appropriate spatial scales.

- i. Investigate the chemical, isotopic, and mineralogical composition of martian surface and near-surface geological materials.
- ii. Interpret the processes that have formed and modified rocks and regolith.

C. Investigate planetary processes that influence habitability.

- i. Assess long-timescale (i.e., 4-billion-year) atmospheric evolution processes.
- ii. Determine present state, distribution, and cycling of water and CO_2.

(*Note: This is not a prioritized list. PSIG judges these investigations to be the science floor for MSL.)

MSL Project Science Integration Group (PSIG)
Payload Considerations

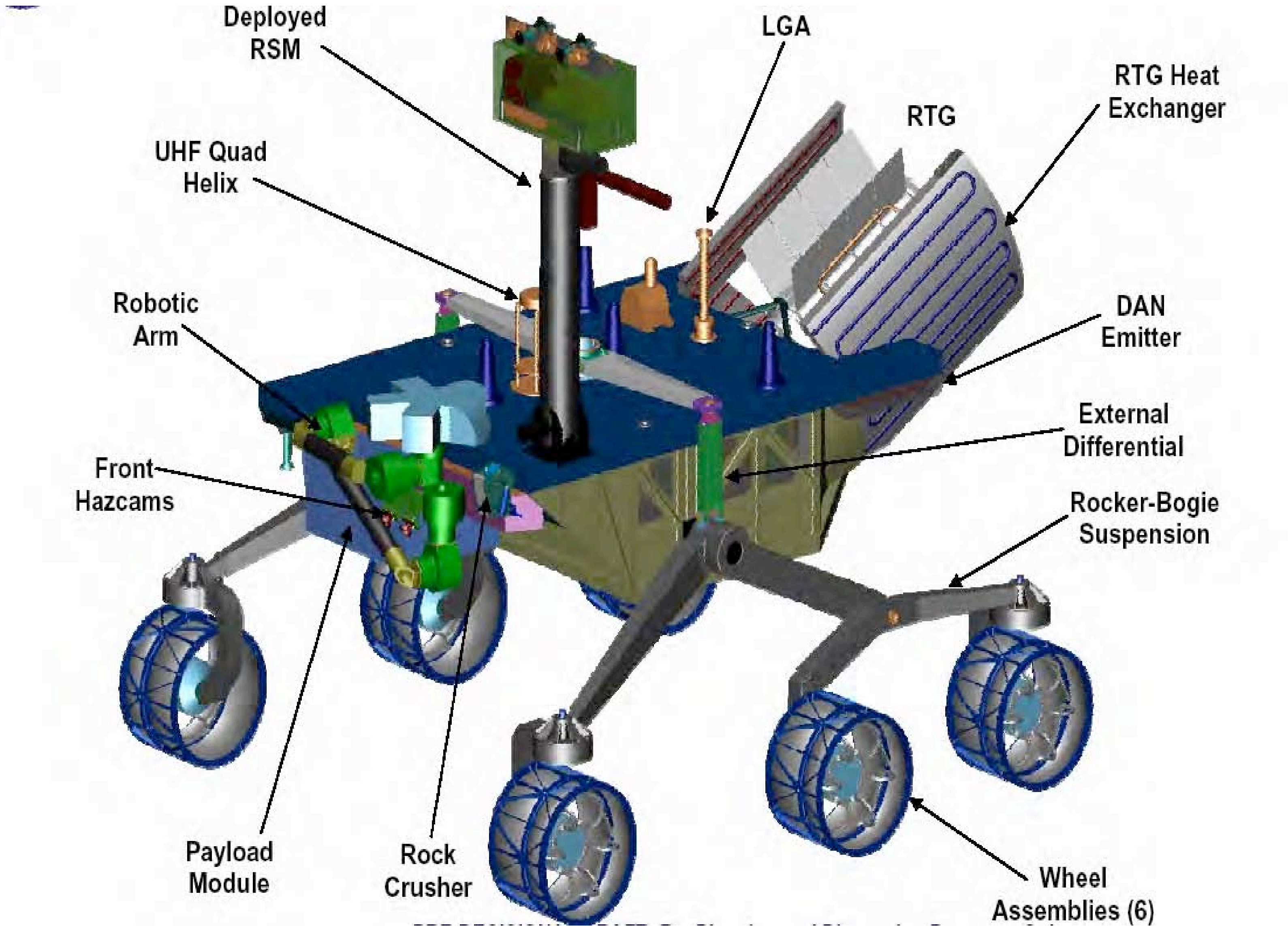
If hardware for alternate missions is identical, mission objectives can be determined by late-breaking discoveries and thus support multiple exploration *Pathways*.

Ancient and Recent Habitability Mission Options Share Common Payload Architectures

1. **Analytical Laboratory**
    1. This is the highest priority element of MSL science mission
    2. Central contribution to Mars exploration by MSL
    3. Detailed in situ analysis of martian samples
    4. Definitive mineralogy, chemistry, and high resolution textural information
    5. Essential to achieving proposed MSL science goals
2. **Remote Sensing Suite**
    1. Reconnaissance and site geological context
    2. Imaging and complementary mineralogy
3. **Contact Instrument Suite**
    1. Sample triage and supplemental target analysis
    2. Microscopic imaging, complementary mineralogy and chemistry
4. **Other Investigations** (Addressing MEPAG priority science)

MSL rover configuration

JPL example MSL configuration



MARS SCIENCE LABORATORY: Dec. 2004 selection - includes the following science instruments or instrument suites:

Cameras

- Mars Science Laboratory Mast Camera (Malin)
- Mars Hand Lens Imager (Edgett)
- Mars Descent Imager (Malin)

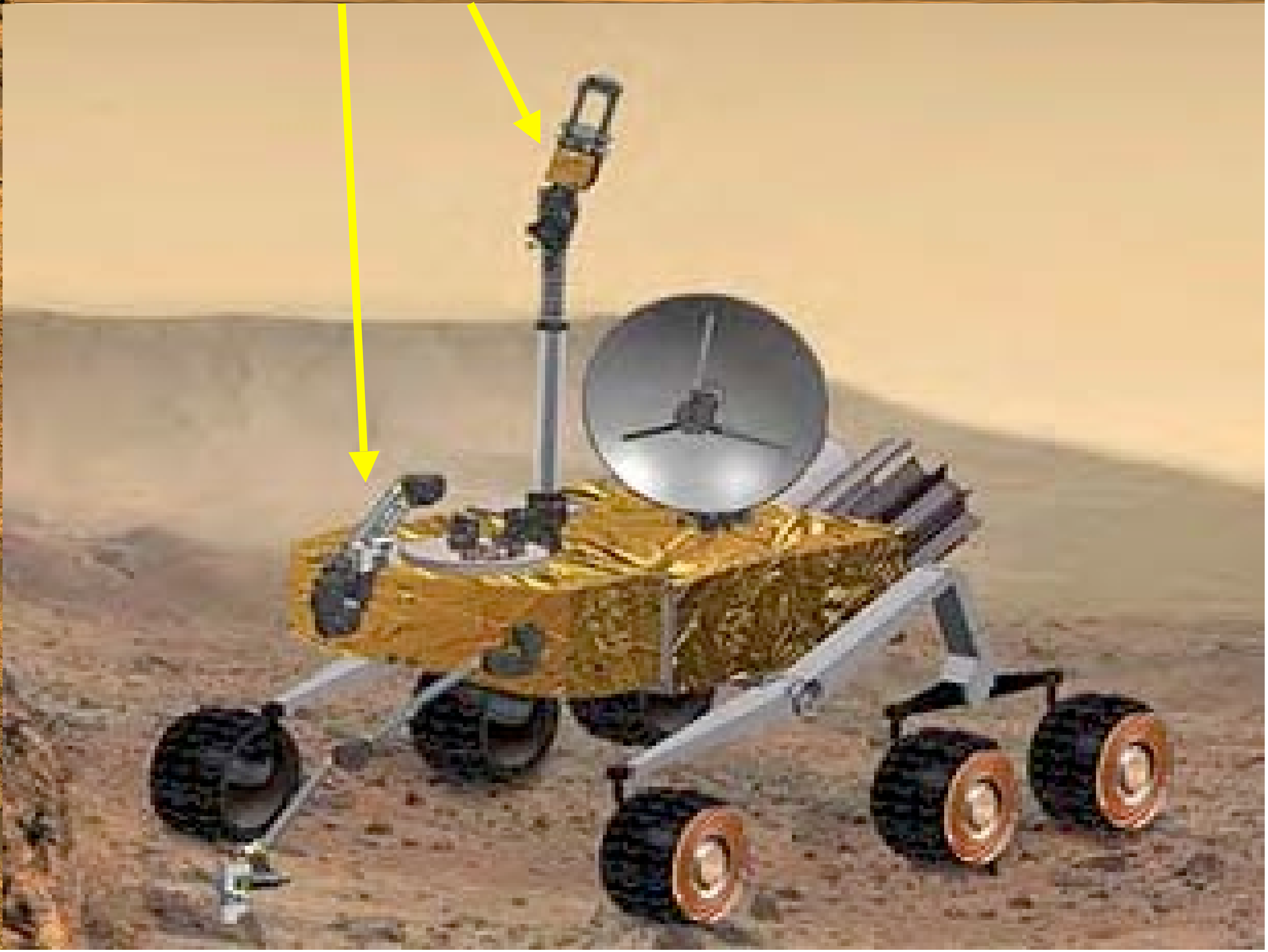
Sample survey and environmental measurements

- Laser Induced Remote Sensing for Chemistry and Micro-Imaging (Wiens)
- Alpha Particle X-Ray Spectrometer (Gellert)
- Radiation Assessment Detector (Hassler)
- Pulsed Neutron Source and Detector (Mitrofanov)
- Meteorological Package with Ultraviolet Sensor (Vasquez)

Analytical laboratory instruments

- X-Ray Diffraction/X-Ray Fluorescence Instrument (Blake)
- Sample Analysis at Mars Suite (Mahaffy)

MSL CAMERAS



MSL cameras – MastCam and Descent Imager

Mike Malin - PI

MastCam expands on abilities of previous lander imaging systems:

- "True" color (same filters as used on digital cameras and camcorders) in addition to narrow-band scientific color
- Zoom/telephoto lens (10X, from 6° to 60° FOV)
- High resolution (150 µm/pixel at 2 m, 10 cm/pxl at 1 km
- High-definition video (720p, MPEG-2, 5-10 frames/sec)
- Large internal storage (256 Mbyte SRAM, 8 Gbyte Flash)

PI Malin also selected for descent imaging camera

Cameras – Mars Hand Lens Imager (MAHLI)

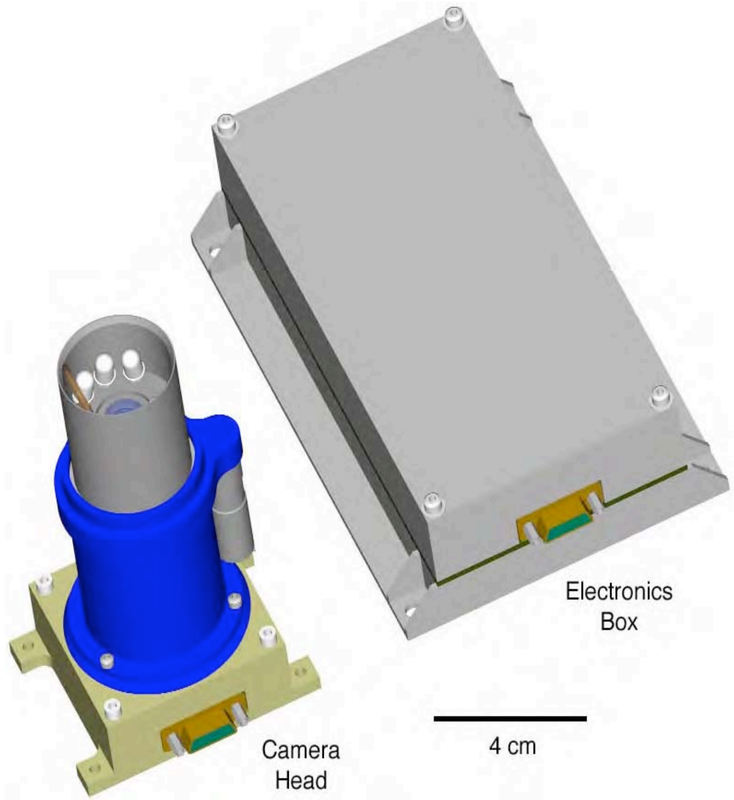
Ken Edgett - PI

Serving as a surrogate for a geologist's hand lens, MAHLI will acquire color images of selected targets at the MSL site at a range of scales from several millimeters to as high as 12.5 μm/pixel.

The data will be used to characterize rocks, fines, and frost or ice at the MSL site on Mars.

The observations, in concert with data from other MSL payload elements, will facilitate interpretation of the nature of past and present martian environments. These observations are the keys to assessing the planet's past and present habitability.

To meet these goals, the instrument will consist of a camera head, mounted on the end of the MSL Sampling Arm (SA), and a separate electronics box, located in the rover Warm Electronics Box (WEB). The camera will produce in-focus images at target distances (from the front end of the optics) of 30 mm to infinity.



Model/rendition of MAHLI from Proposal.

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MAHLI science objectives

Primary Objective:

Characterize and determine the details of the history and processes, particularly as they pertain to habitability, recorded in geologic material at micrometer to centimeter scale at the MSL site.

Specific Objectives:

1. **Rocks.** Examine rocks (outcrops and clasts ≥ 4 mm) and the results of interaction of rover hardware with rocks to determine texture, morphology, structure, mineralogy, stratigraphy; and contribute to determination of rock type, history, depositional, diagenetic, and weathering processes.

2. **Fines.** Examine regolith fines (clasts ≤ 4 mm) to determine the processes that acted on these materials and individual grains within them, including physical and mechanical properties, the results of rover hardware interaction with fines, plus stratigraphy, texture, mineralogy, and depositional processes.

3. **Frost and Ice.** Characterize frost or ice, if present, to determine texture, morphology, thickness, and relation to regolith, including stratigraphic position, and, if possible, changes over time.

4. **Facilitate Other MSL Science.** Help MSL science teams identify material to be collected for, and characterize samples prior to delivery to, the MSL Analytical Laboratory; document the attributes of surfaces examined by other MSL Contact Instruments; and support other MSL instruments that may need hand lens-scale imaging.

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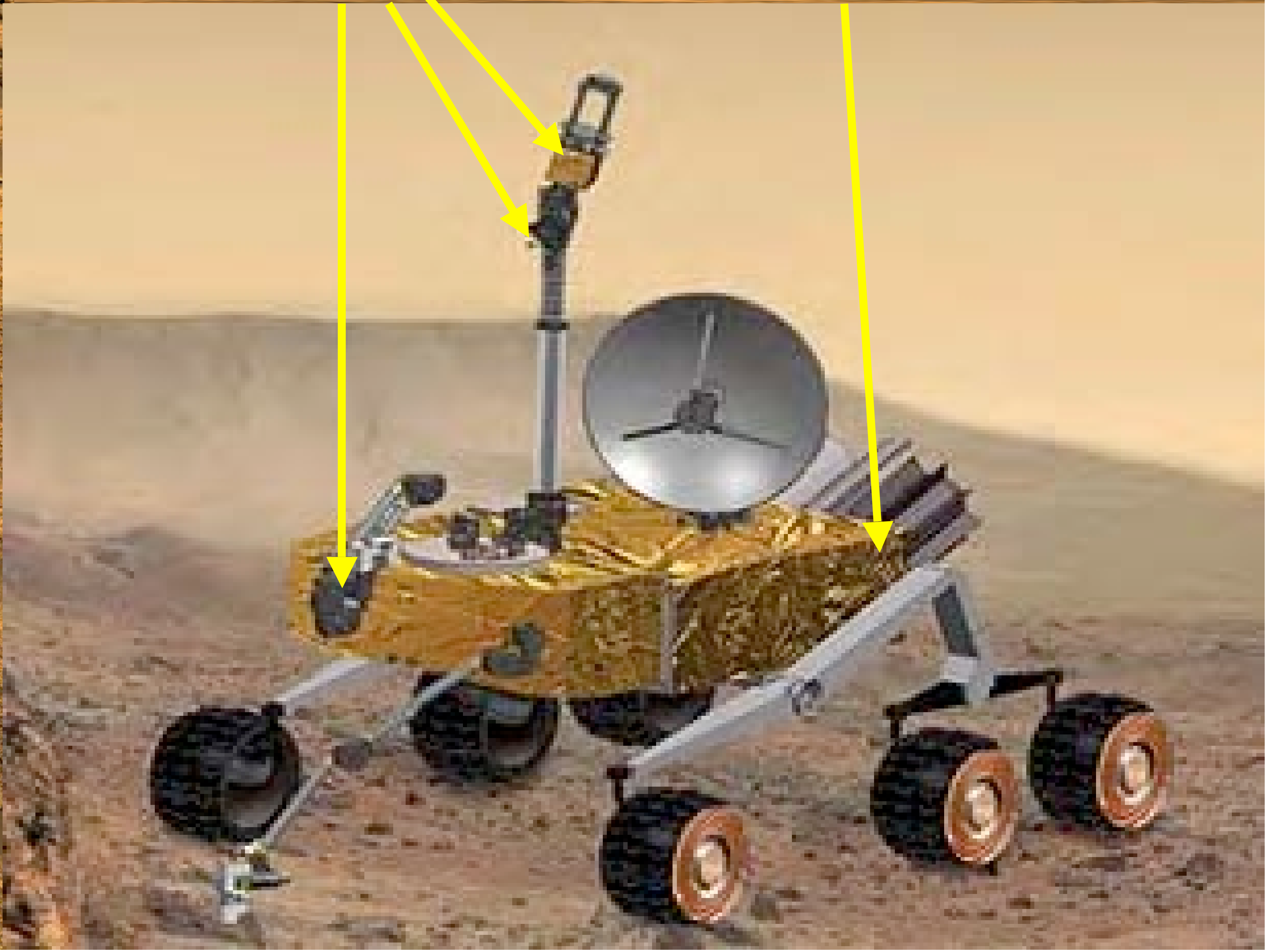
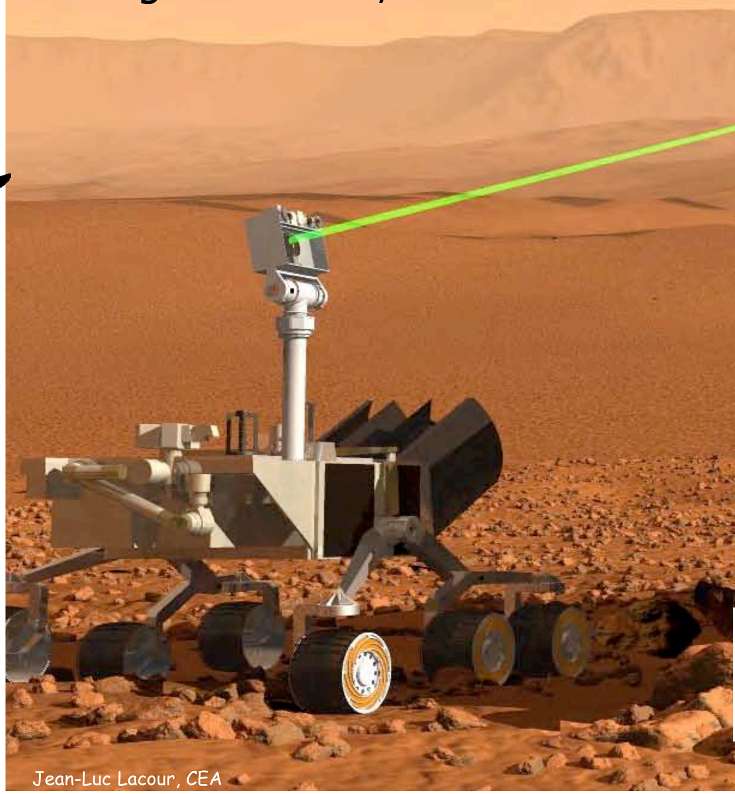
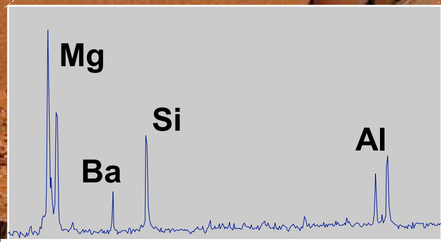
Sample survey and environmental measurements



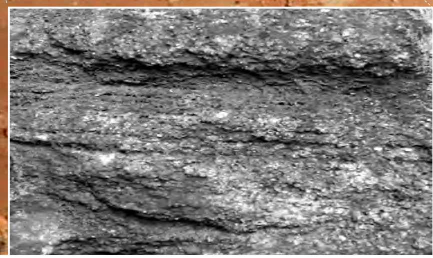
ChemCam

- 2 Instruments: LIBS + Remote Micro-Imaging
- Dust-Free Remote Elemental Compositions
- Smallest Analytical Spot Size (< 1 mm) on MSL
- Detection of All Elements, Including H,C,N,O
- Depth Profile Capability to ~1 mm Depth
- Collaboration Between CESR, France, and Los Alamos National Laboratory
  Roger C. Wiens, PI



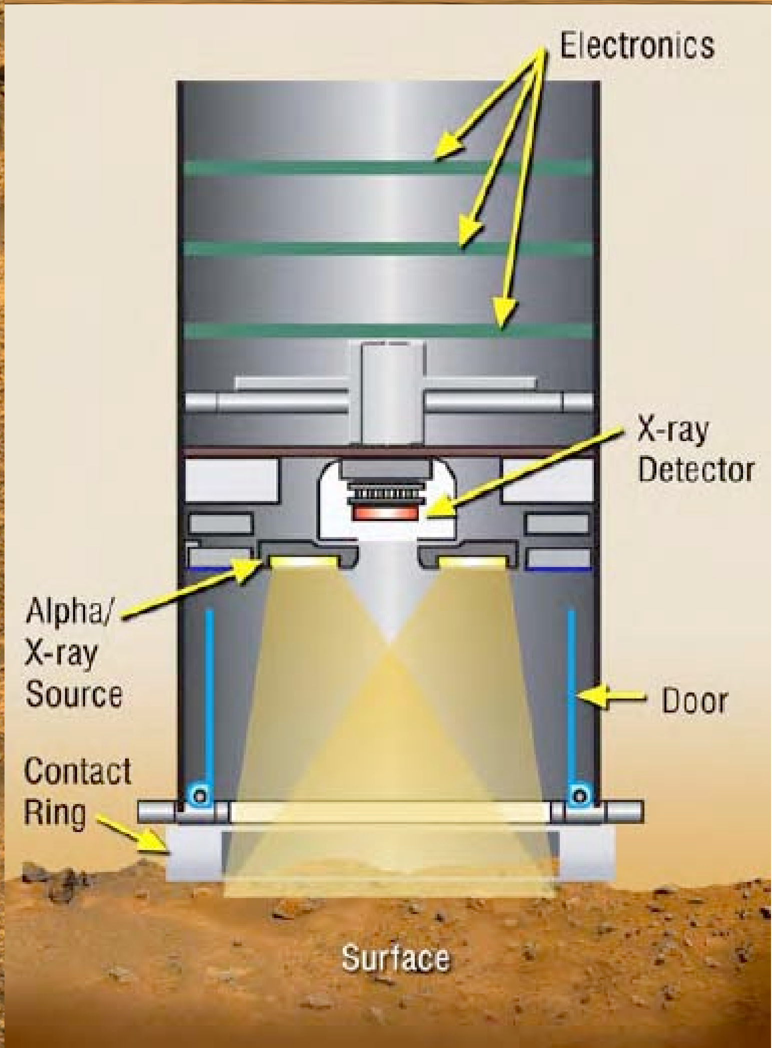


Elemental Abundances from Laser-Induced Breakdown Spectroscopy (LIBS)



Most Detailed Remote Images Ever from the Remote Micro-Imager (RMI)

APXS



PI: Ralf Gellert

The Alpha-Particle-Xray-Spectrometer (APXS)

- **Contact X-ray spectroscopy (characteristic elemental peaks)**
- **Determines rock forming elements from Na to Br with low detection limits (0.1% to 50 PPM weight percents)**
- **method is a combination of PIXE and XRF**

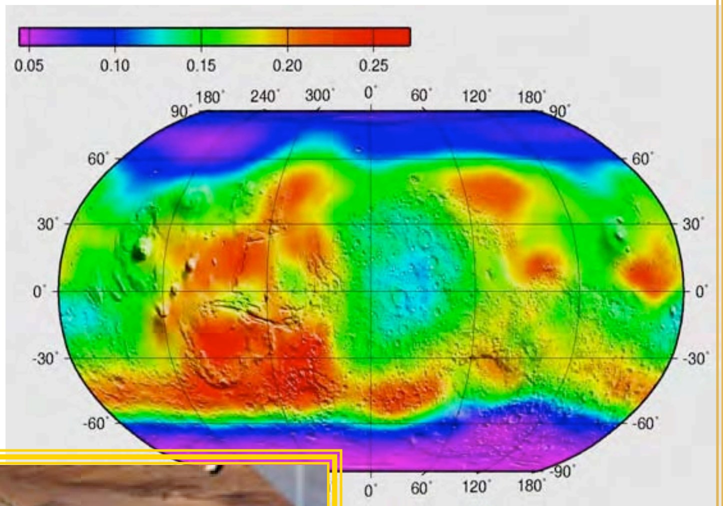
Terrestial equivalent standard applications

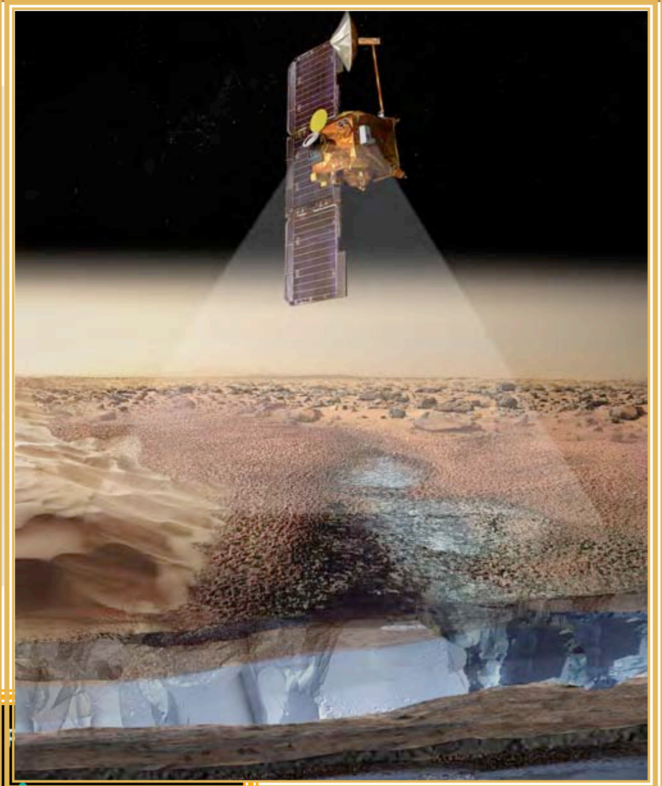
PIXE : Particle induced X-Ray Excitation (_ , Proton , ~ MeV)
required : Particle Accelerator, Sample preparation

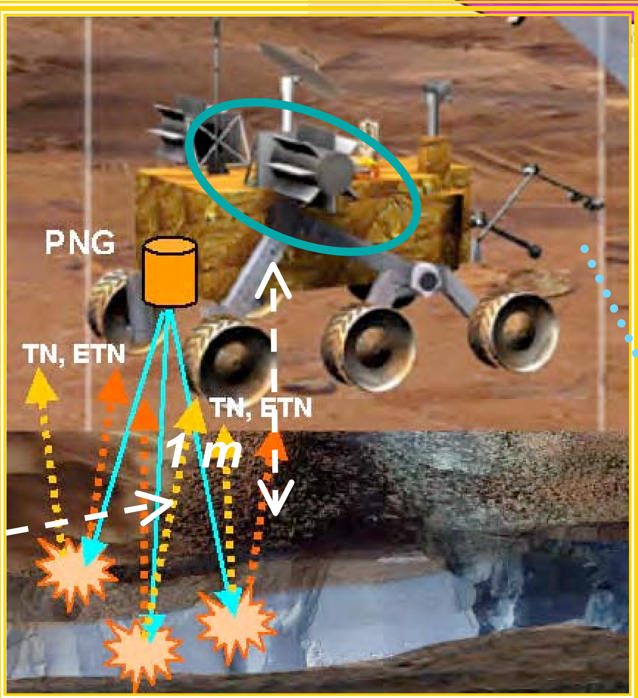
XRF : X-ray Fluorescence (~ 10 keV _ radiation)
required : Xray tube, powdering and melting samples

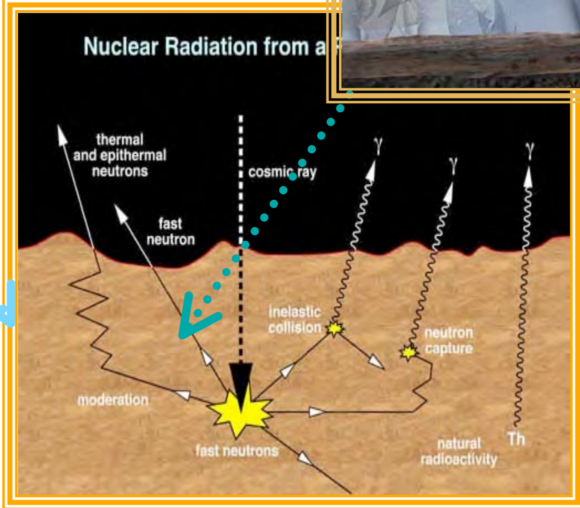
Dynamic Albedo of Neutrons (DAN)

PI: Igor Mitrofanov

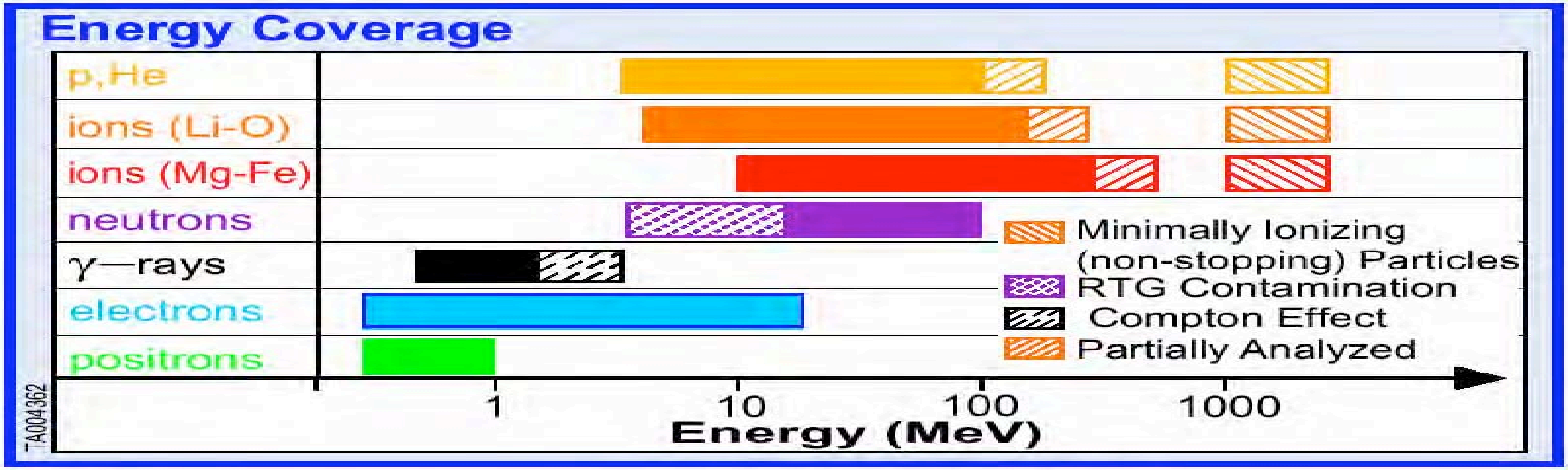


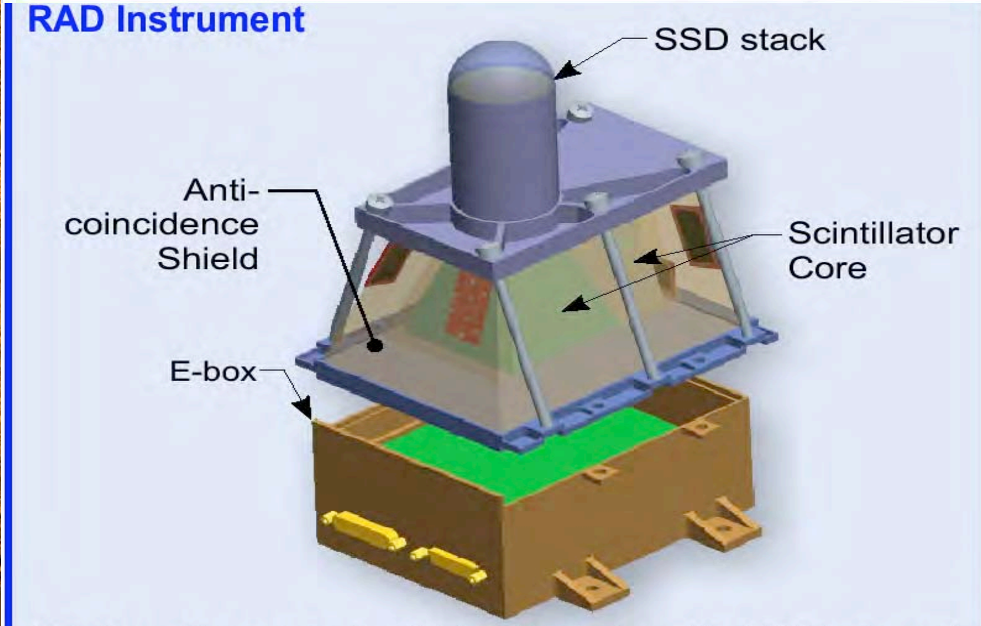






Radiation Assessment Detector (RAD)





3-D view of the compact, weight-saving design of the RAD instrument. The electronics box provides a base for the sensor unit and the lightweight Ni housing provides sufficient stability for the sensor without obstructing the neutron and gamma radiation environment.

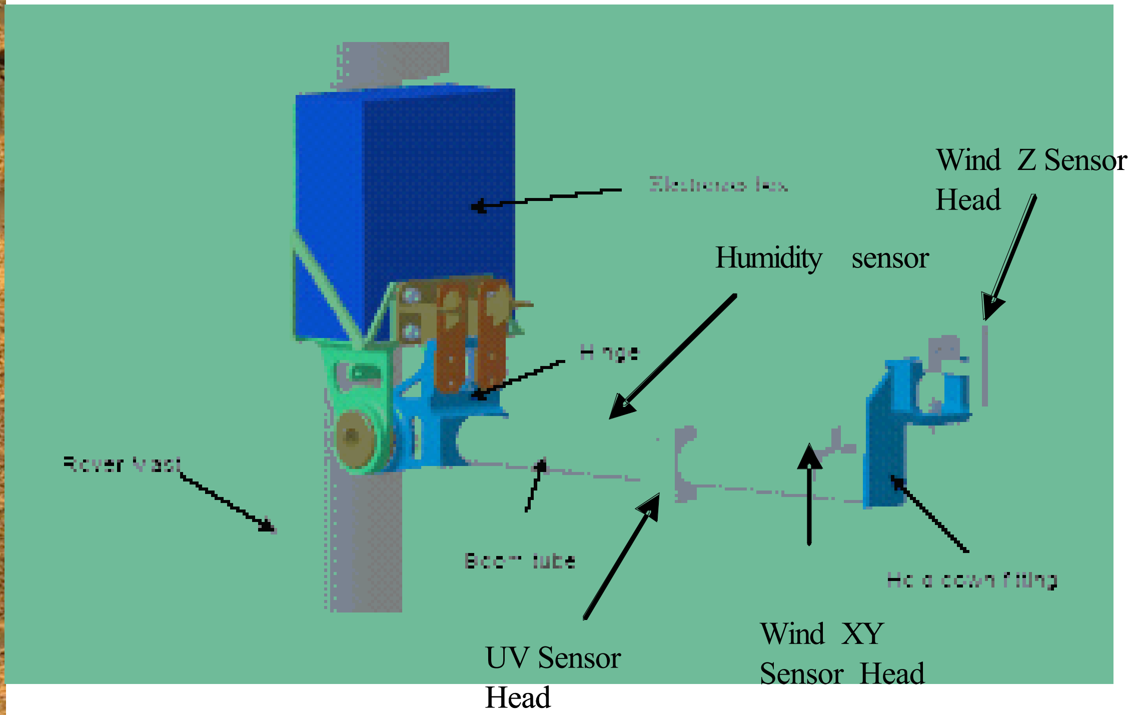
PI: Don Hassler

MSL RAD Scientific Objectives

To characterize fully the broad spectrum of radiation at the surface of Mars.

Weather station

PI: Luis Vazquez

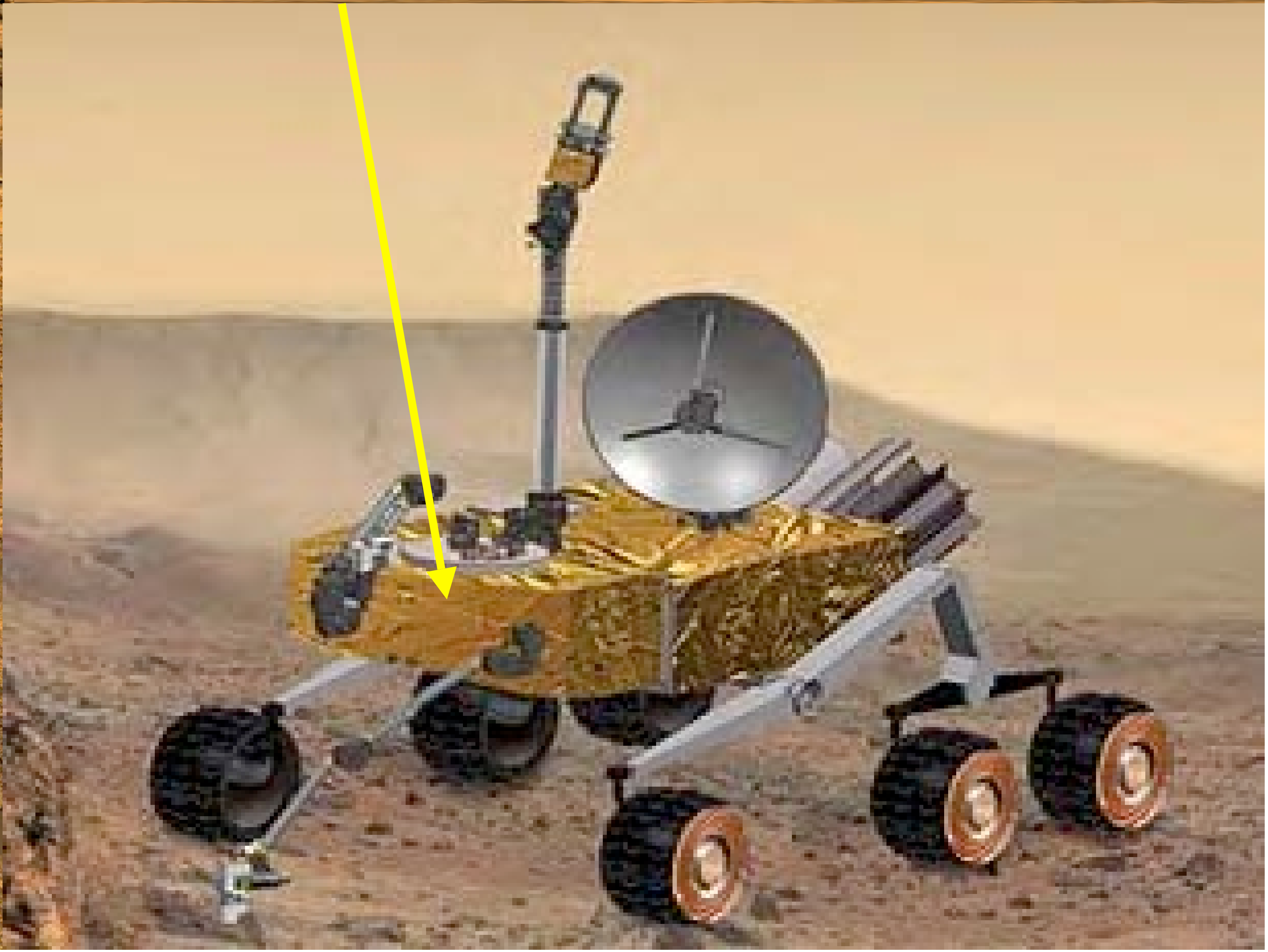


Measurements of Pressure, Temperature (Air and Ground), Humidity, Wind and UV.

Temperature measurement at two different heights while the wind, pressure, humidity and UV radiation will be measured at one level.

Ground Temperature enables: ***Better understanding of the thermal discontinuity at the boundary layer; Flow of radiation emitted by the surface; Thermal inertia of the surface; Exchange of water between the atmosphere and adsorbed water in the regolith; Calibration of models***

Analytical Laboratory



AO requirements for MSL Analytical Laboratory

Essential measurements in approximate priority order:

1. Nature, abundance, oxidation state, and isotopic properties of carbon compounds (organic and inorganic) over a range of molecular weights (depending on landing site: soils, ices, or interiors of rocks).

2. Definitive mineralogy and chemical composition (emphasize aqueous processes).

3. Molecular configuration and isotopic composition of elements other than C that are relevant to life (H, N, O, P, S) in rocks, soils, the atmosphere, and, possibly, ice.

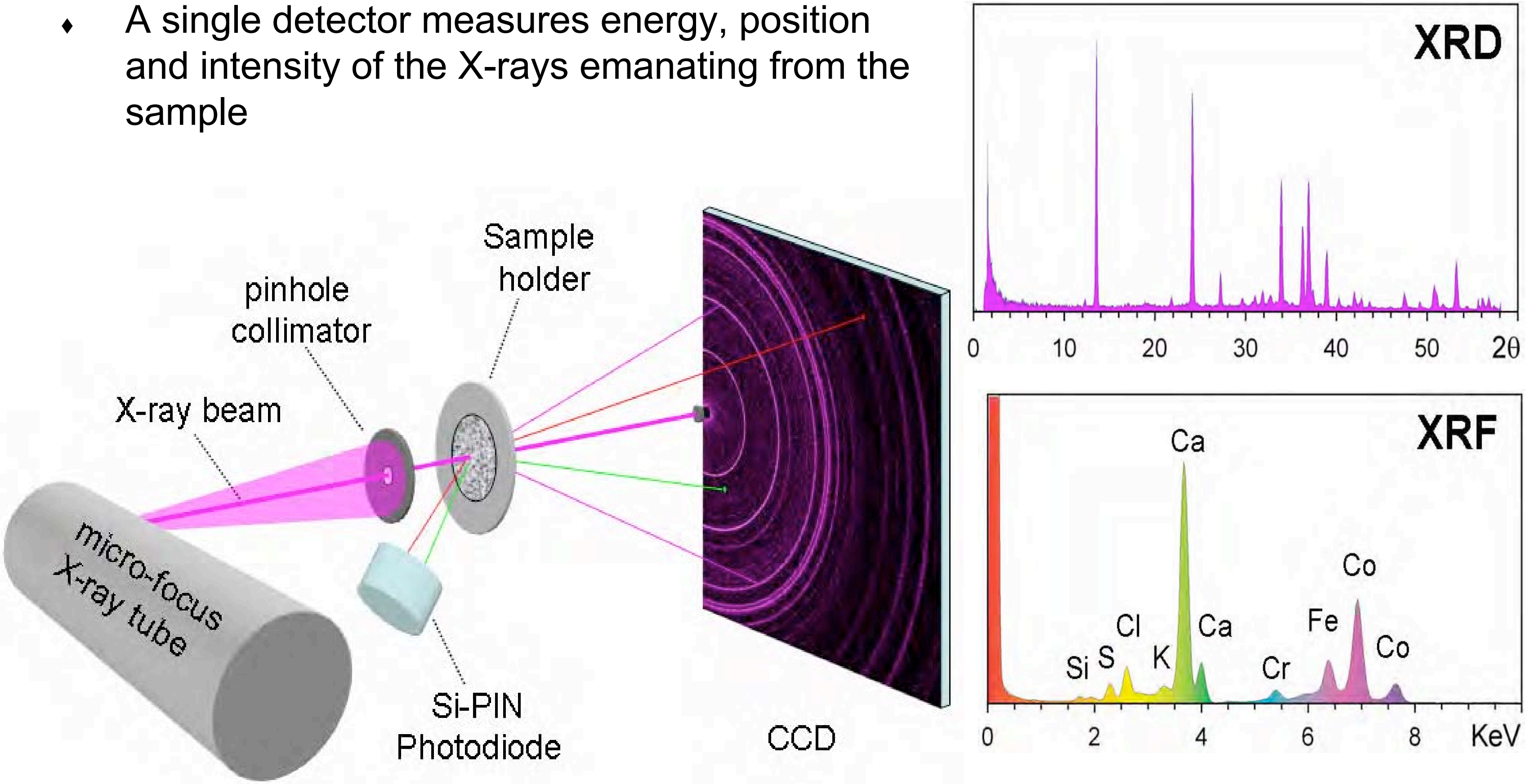
4. Noble gas concentrations and isotope ratios.

5. Microscopy (basic geologic context, and record possible morphological biosignatures).

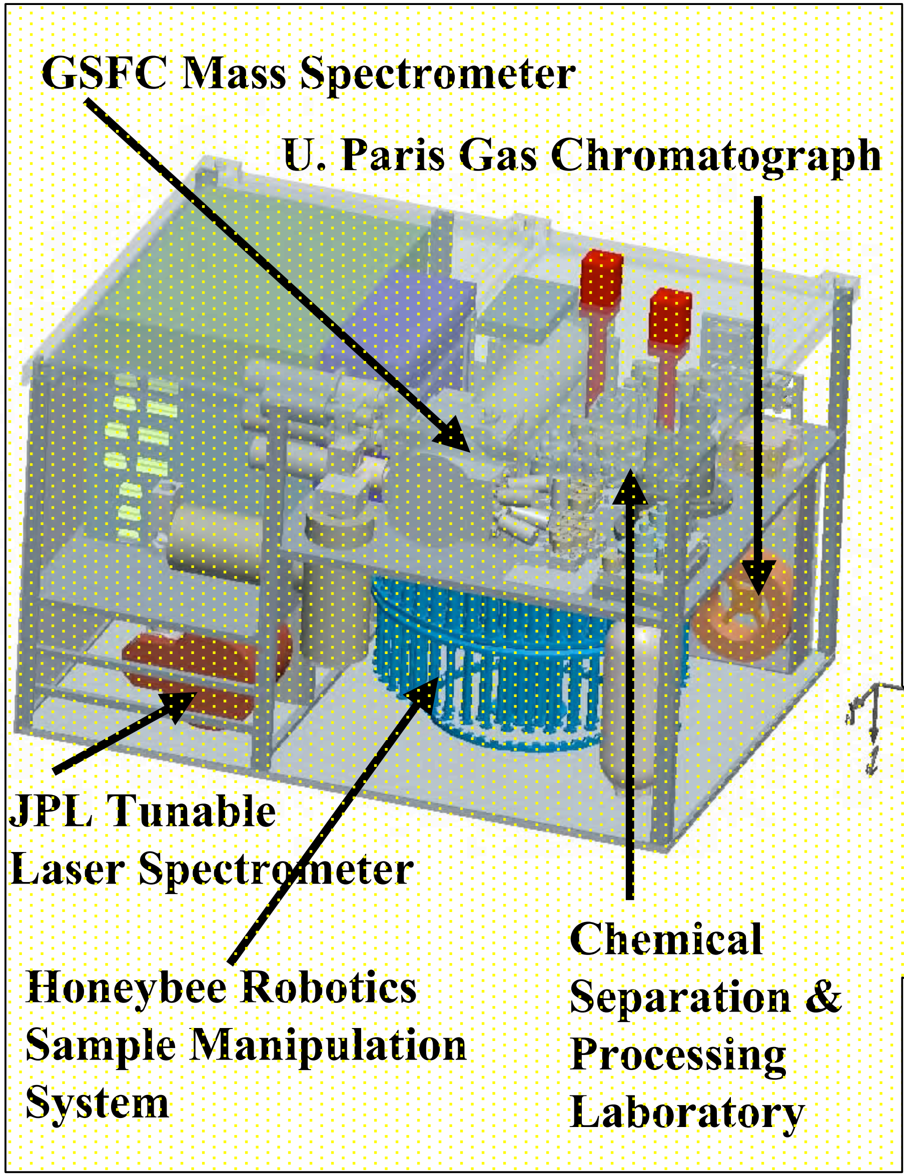
Analytical Laboratory - CheMin

PI: David Blake
Measurements: X-ray Diffraction/X-ray Fluorescence (XRD/XRF)
Science goals: Definitive Mineralogy

- A single detector measures energy, position and intensity of the X-rays emanating from the sample

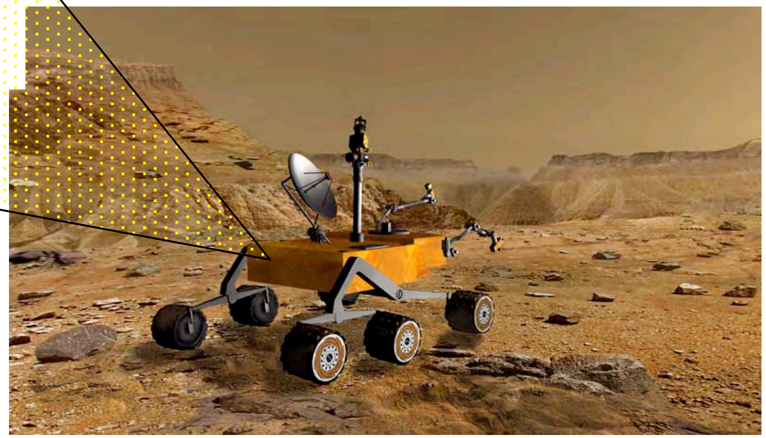


Analytical Laboratory - SAM



SAM SCIENCE GOALS

- Search for organic compounds of biotic and prebiotic relevance and explore sources and destruction paths for carbon compounds.
- Reveal chemical state of other light elements that are important for life as we know it on Earth
- Study habitability of Mars by measuring oxidants such as hydrogen peroxide
- Investigate atmosphere and climate evolution through isotope measurements of noble gases and light elements



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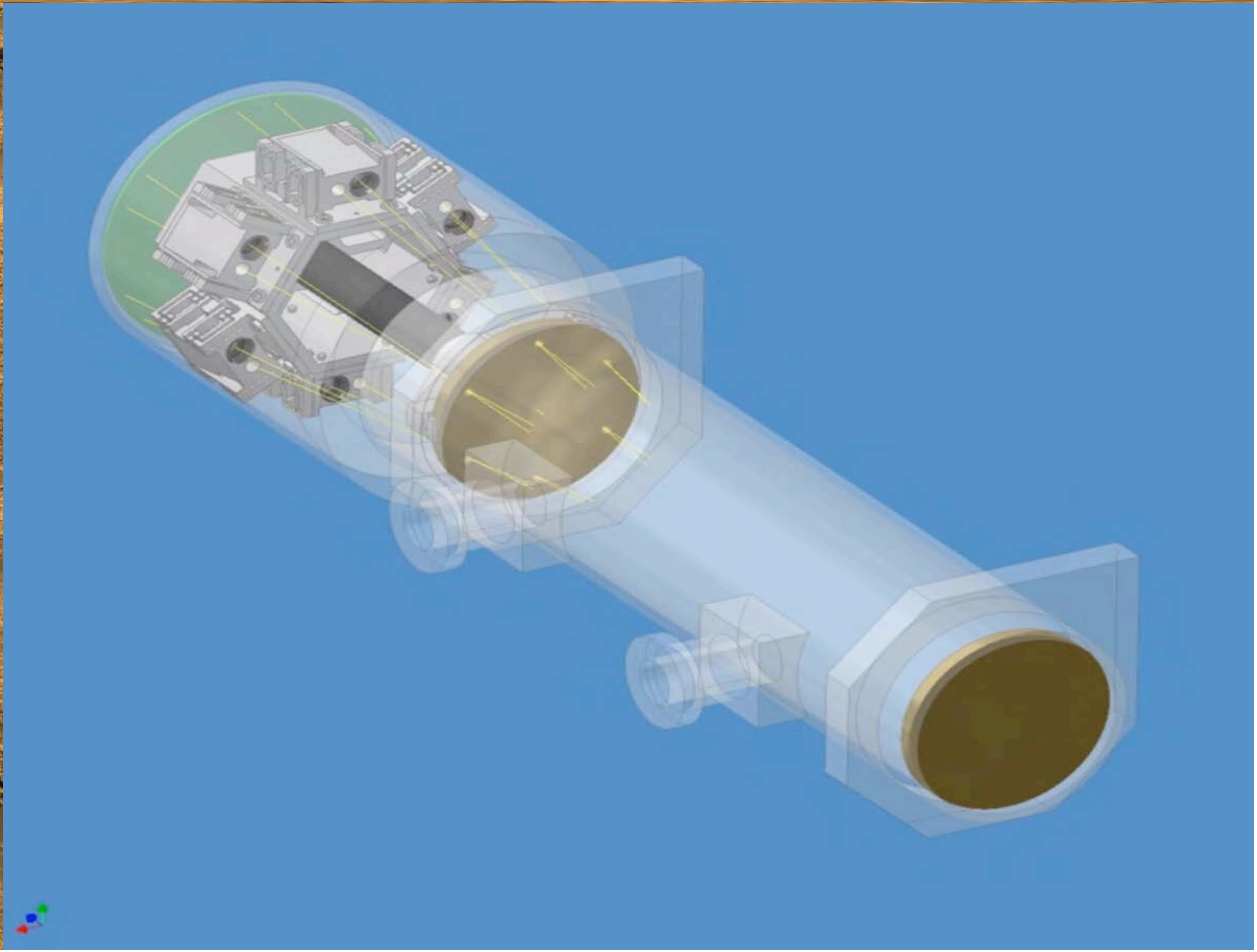
SAM GCMS relative to Viking

	Viking	SAM	Science Benefit
Pyrolysis Ovens			
No. of sample cups	3	78	More samples analyzed – each cup can be used multiple times
Temperature	50, 200, 350, or 500ºC	Continuous heating up to 1100ºC	Identification of mineral decomposition products
Gas Chromatography			
Columns	Poly MPE-Tenax	Molsieve 5A carbo-bond, MXT 1,5, MXT PLOT U, RTX 5 Amine, Chirasil-Val	Analysis of a wider range of organics, noble gases, VOCs, derivatized compounds, enantiomers and amines
Derivatization	No	Yes, MTBSTFA	Transforms key organic biomarkers
Mass Spectrometer			
Mass range (Da)	12 - 200	2 - 535	Mass identification of a wider range of species; derivatized compounds
High throughput pumps	no	yes	Increase in sensitivity
Static/dynamic modes	Dynamic only	Static or dynamic	High precision isotopes
Direct EGA monitoring	no	yes	Detect complex, less volatile species

SAM Tunable Laser Spectrometer



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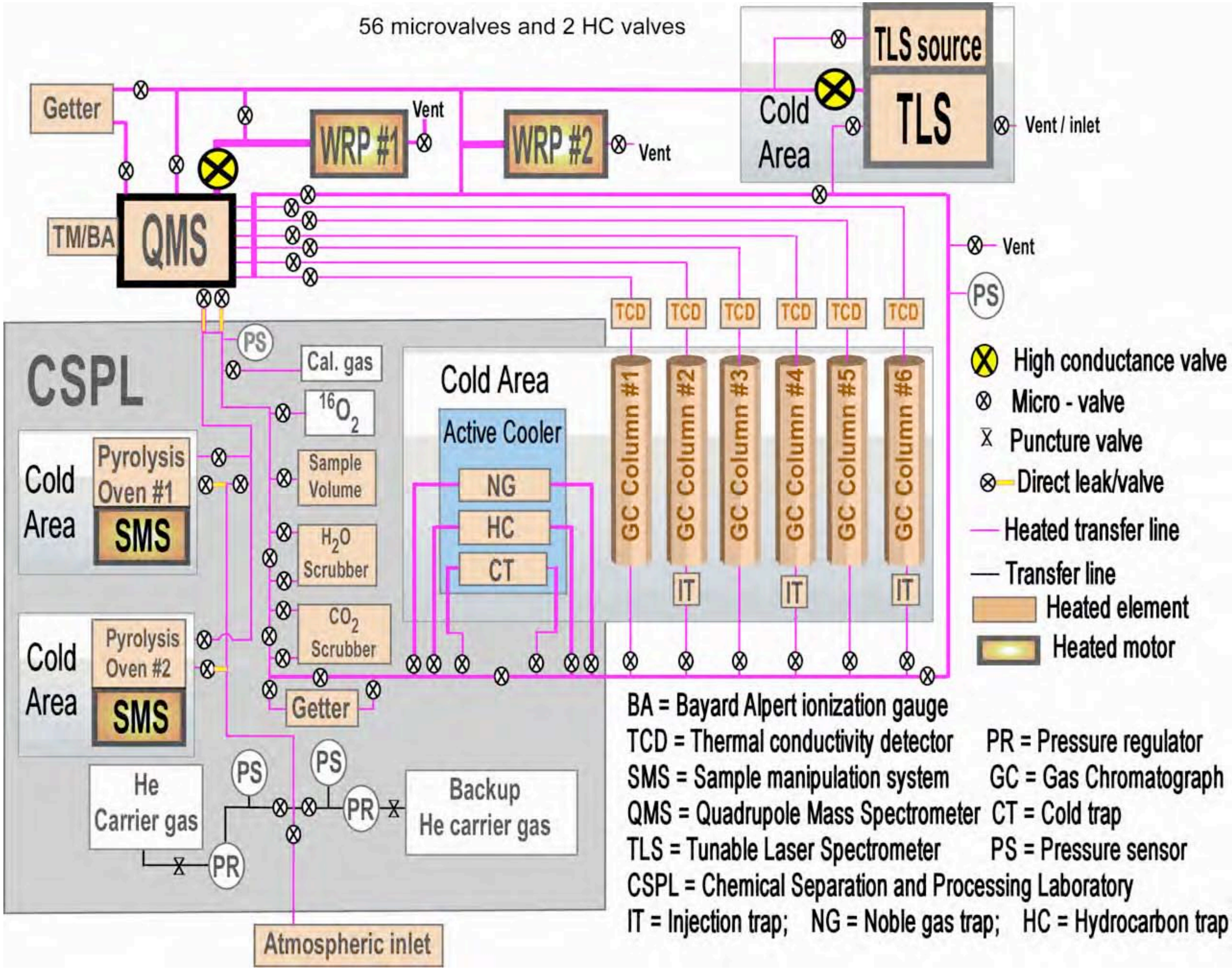
SAM Tunable Laser Spectrometer (TLS)

Channel	Molecules	Wavelength (_m)	Expected mixing ratio	Minimum-detectable mixing ratio	
					With SAM pre-concentration
Channel 1: **High sensitivity water**	**H_2O**	**1.87**	few to hundreds ppm in air	30 ppbv water (range to 10,000 ppmv)	
Channel 2: **Water isotopes**	**$H_2{}^{16}O$, HDO, $H_2{}^{17}O$, $H_2{}^{18}O$**	**2.64**	N/A	Needs 200 ppmv water Delta-D to 10 per mil Delta-18O to 2 per mil Delta-17O to 5 per mil	Required
Channel 3: **CO2 and isotopic CO2**	**CO_2 $OC^{18}O$, $^{13}CO_2$**	**2.78**	~96% or less	4 ppmv Delta-13C to few per mil Delta-18O to 10 per mil	
Channel 4: **Methane & 13C methane**	**CH_4 $^{13}CH_4$**	**3.27**	10-250 ppbv	<1 ppbv Delta-13C to 10 per mil	20 pptv Required
Channel 5: **CO and 13CO Carbonyl sulfide**	**CO, ^{13}CO $OC^{32}S$, $OC^{34}S$**	**4.83**	0.07% in air < 10 ppbv	5 ppbv 0.3 ppbv Delta-34S to few per mil	
Channel 6: **Hydrogen peroxide**	**H_2O_2**	**7.80**	20 ppbv or more in dust devils	2 ppbv	<1 ppbv
Channel A: **Sulfur dioxide**	**SO_2**	**7.4**	10 ppb	2 ppbv	0.5 ppbv
Channel B: **Formaldehyde**	**H_2CO**	**3.55**	< 500 ppb?	2 ppbv	0.5 ppbv

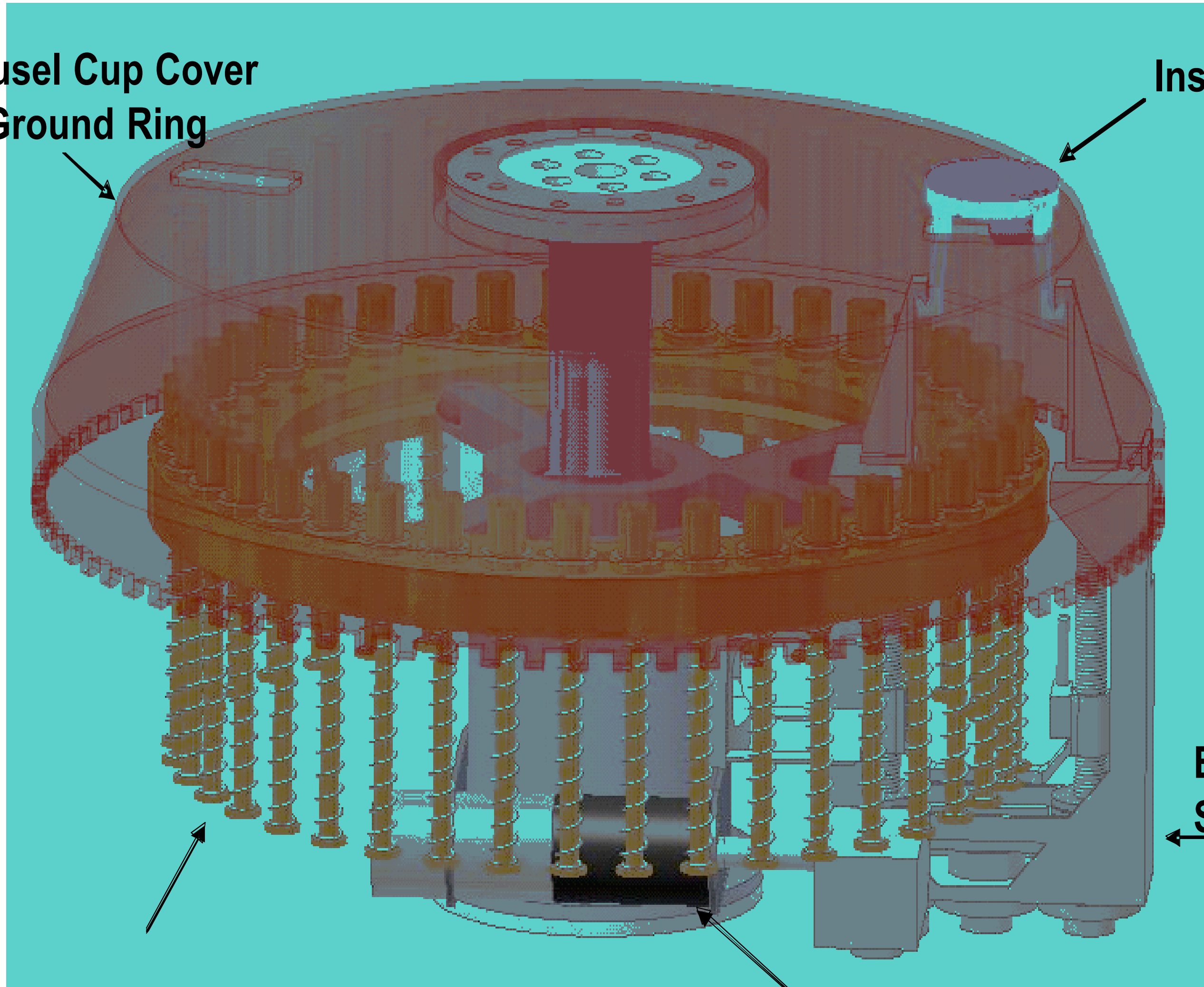
SAM gas flow diagram



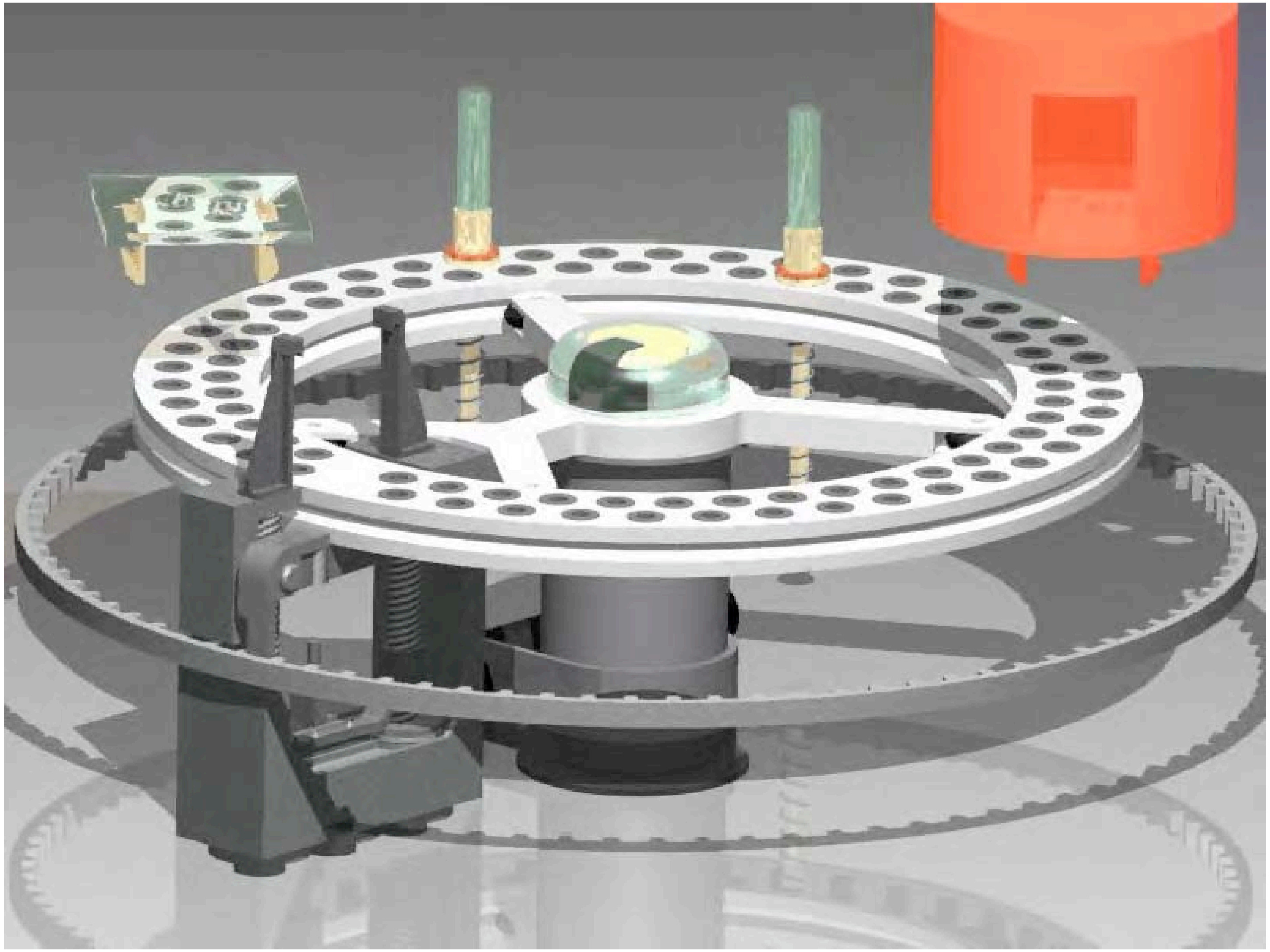
BA = Bayard Alpert ionization gauge
TCD = Thermal conductivity detector
PR = Pressure regulator
SMS = Sample manipulation system
GC = Gas Chromatograph
QMS = Quadrupole Mass Spectrometer
CT = Cold trap
TLS = Tunable Laser Spectrometer
PS = Pressure sensor
CSPL = Chemical Separation and Processing Laboratory
IT = Injection trap; NG = Noble gas trap; HC = Hydrocarbon trap

MSL

Baseline SMS configuration



SMS gets sample



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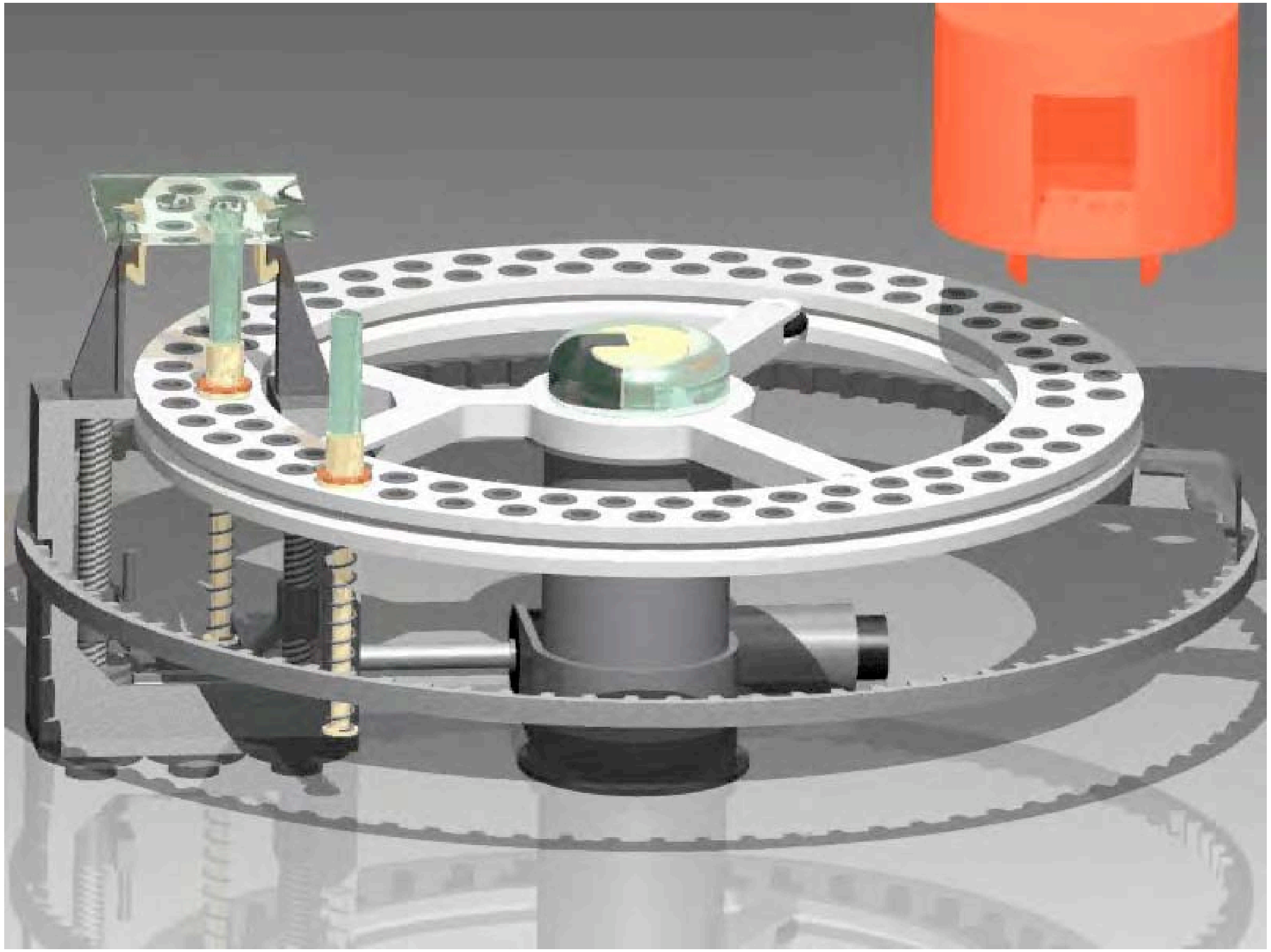
SMS transports sample to pyrolysis station



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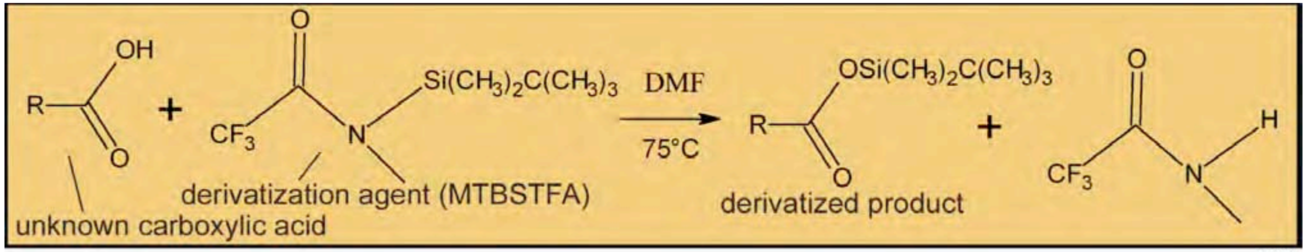
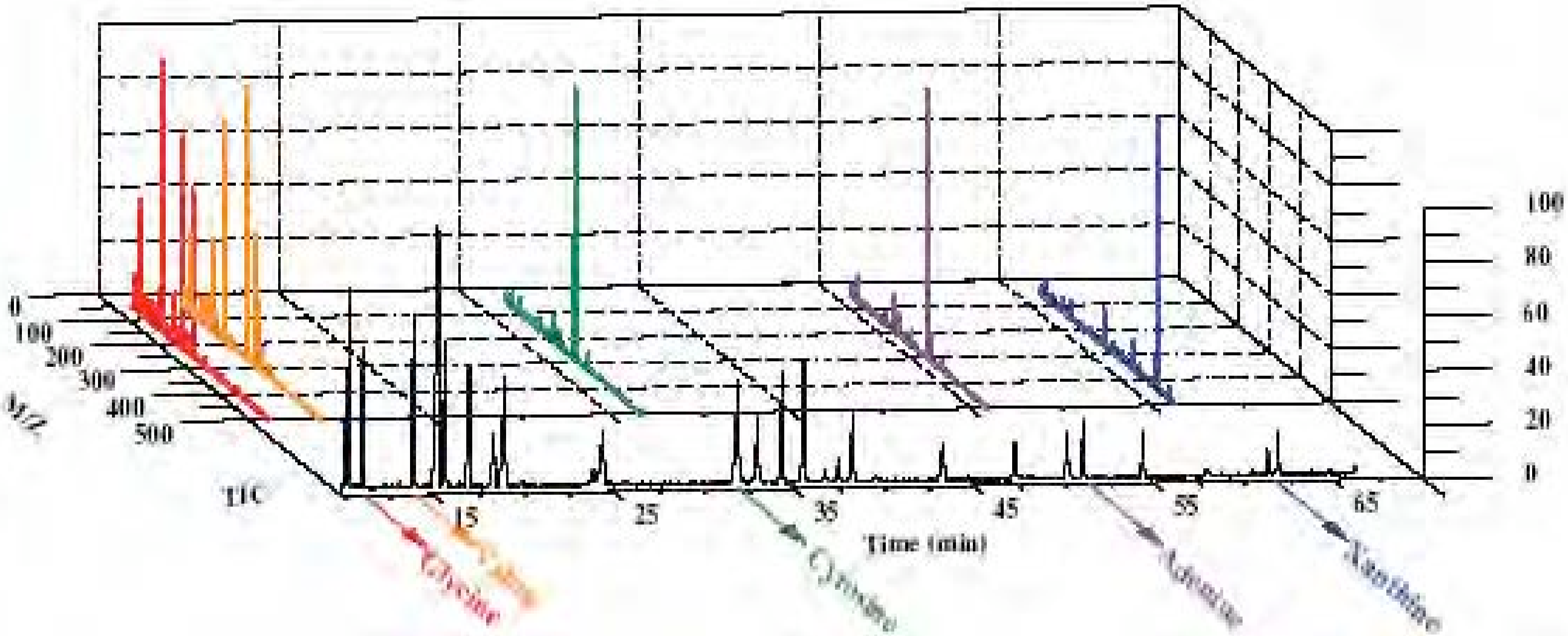
Low temperature organic extraction/derivatization



SM009

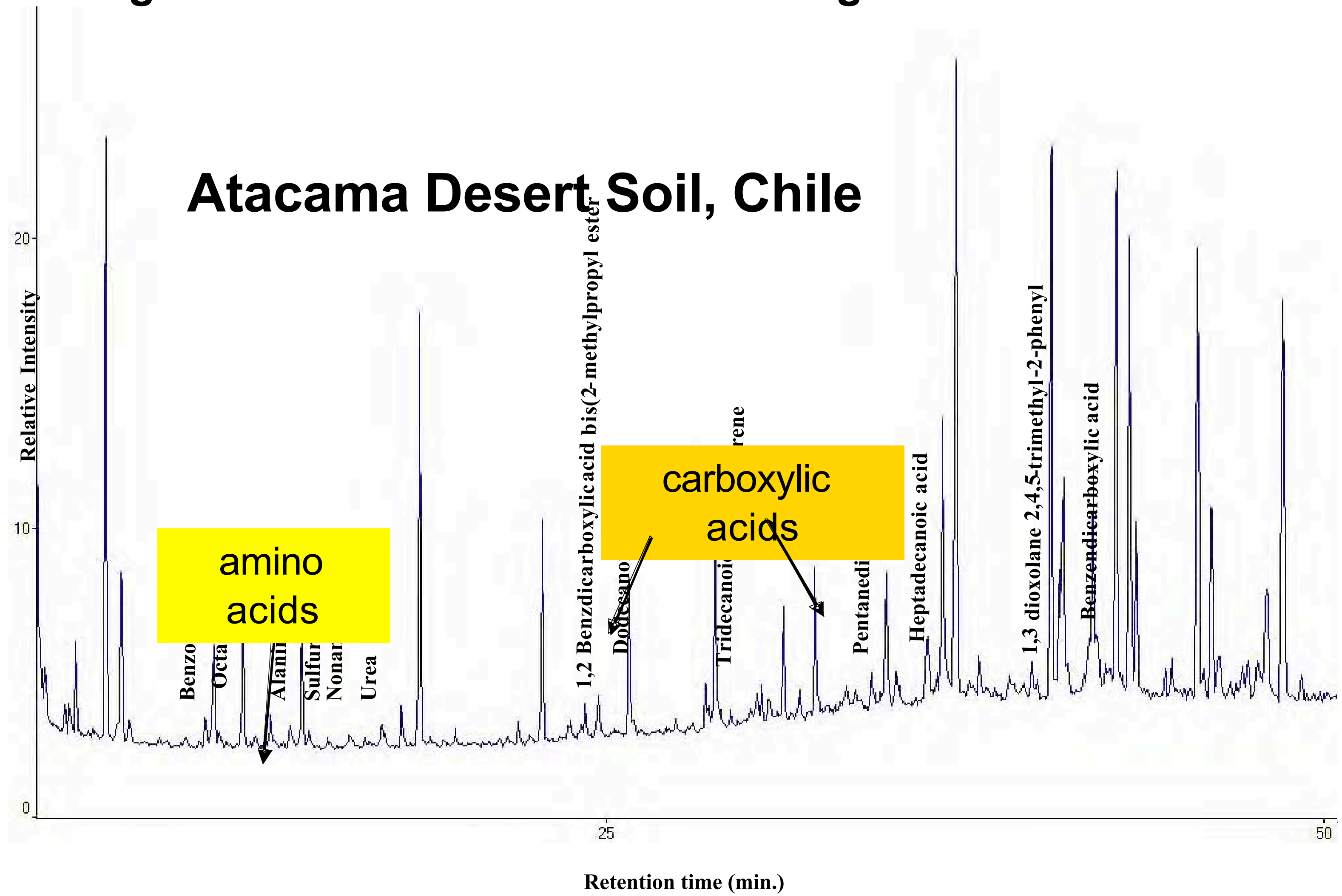


SM032

A wide range of organic compounds (amino acids, nucleobases, carboxylic acids, amines) relevant to life can be detected by GCMS after chemical derivatization – our "magic bullet" is N,N-Methyl-tert.-butyl(dimethylsilyl)trifluoroacetamide

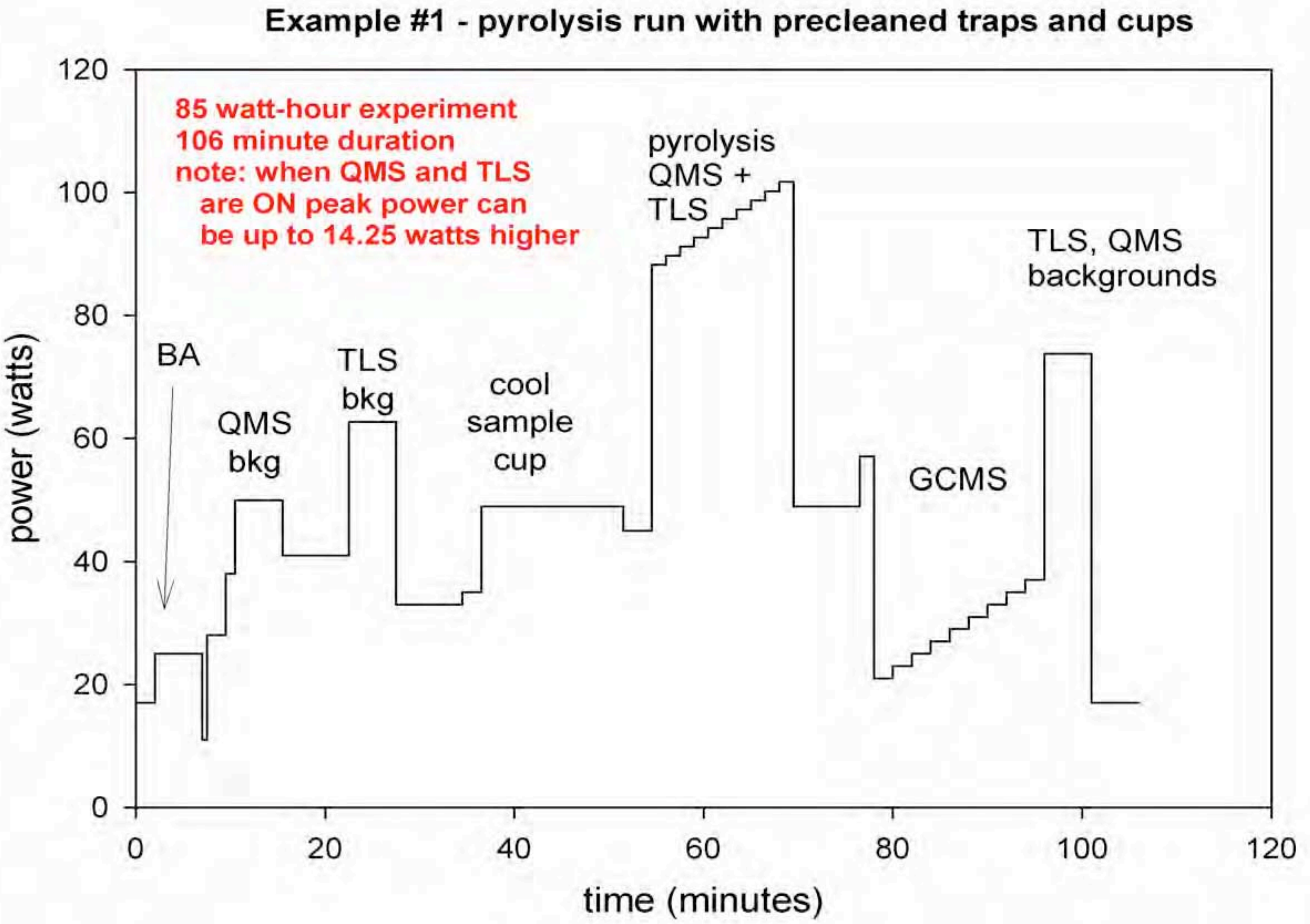
MSL

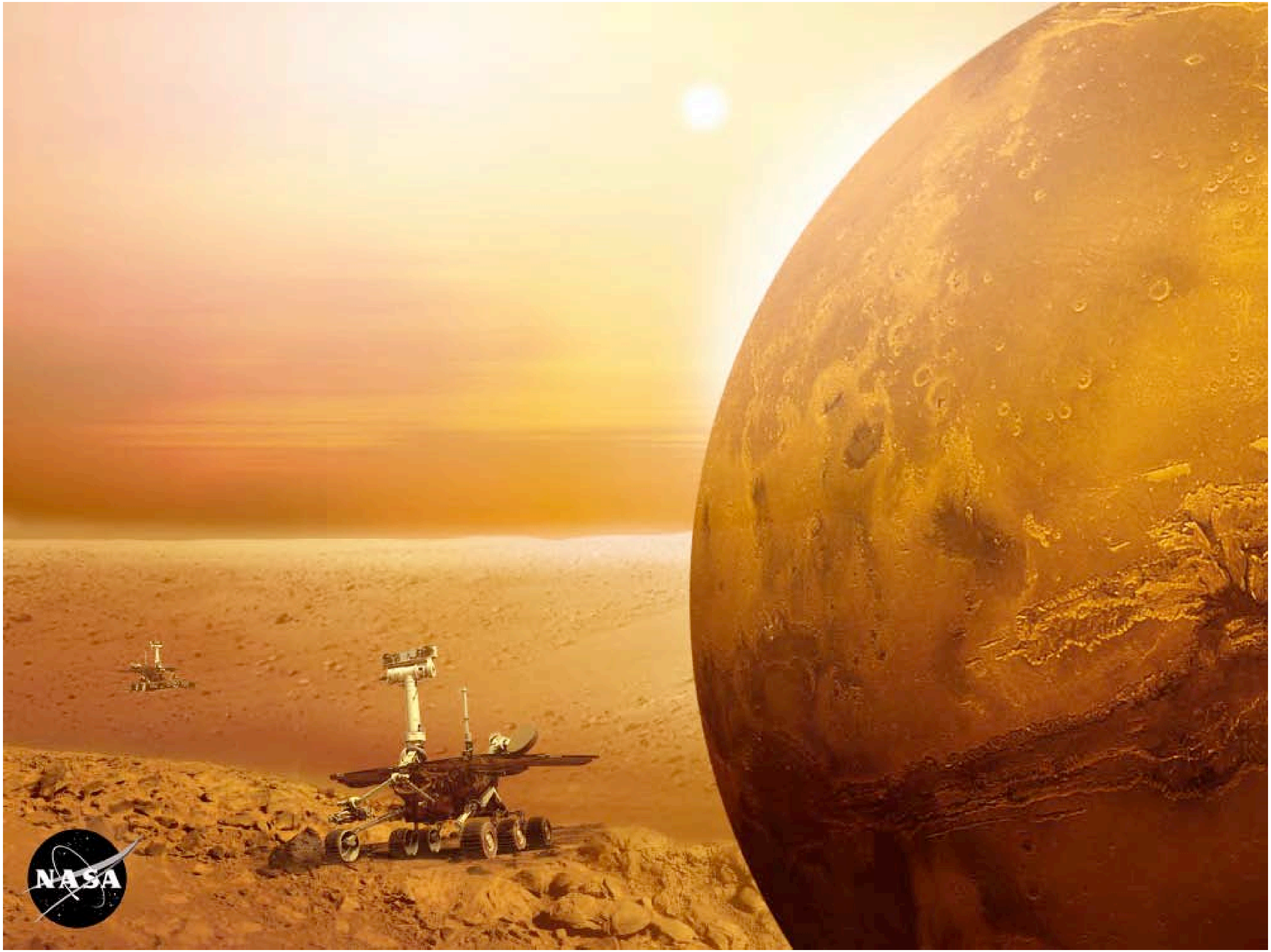
Organics extracted from Mars Analog



Critical measurement scope derived from low temperature extraction

SAM sequence example – night time analysis with TLS going full blast on all 6 channels




NASA